Geomorphic Contrasts Within the Koolau Range of Oahu, Hawaii

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LAYMEN AS WELL AS GEOLOGISTS have observed various striking topographic contrasts between the southeastern and the northwestern parts of the Koolau Range of the island of Oahu, Hawaii. These familiar contrasts are discussed in this paper, but attention is also called to certain less obvious contrasts, and to the bearing of all the contrasts on the geologic history of the Koolau Range.

I am indebted to Messrs. Doak C. Cox, Stephen B. Jones, Gordon A. Macdonald, Erik Palmer, Howard A. Powers, and Horace Winchell for careful reading of a draft and for valuable criticisms and suggestions.

In addition to the usual placing of references to the literature and to figures by items in parentheses, it was thought well to give help in locating of unfamiliar place names. Therefore references to the figures on which places may be found are given in parentheses after the place name in the text.

A chart was made of the 100-fathom and 200-fathom submarine contour lines around Oahu, but it showed no discernable contrasts between the two parts of the Koolau Range.

THE WINDWARD SIDE

Simplified maps of four parts of the windward, or northeast, side of the Koolau Range with a contour interval of 500 feet show significant contrasts (Fig. 1A–E). The southeastern part has rather continuous, high cliffs, that curve inland a little to form wide alcoves. Davis (1928: 171) aptly described these windward-facing cliffs as "receding in several bights between blunt cusps." At Waimanalo and Kailua (Fig. 1A) the alcoves or bights are a mile and a half to two miles wide, but those from Haiku Valley to Waiahole (Fig. 1B) are only a mile or a little less in width. In both these areas the reentrant depths of the alcoves are about three-quarters of a mile, and, because of the steepness of the cliffs, the 500- and 2,000-foot contour lines are in general only half a mile apart. For much of the way, a smooth curve generalizing the 500-foot contour line would depart from the actual contour lines by only a third or a half of a mile.

In the area from Kualoa to Kaluanui (Fig. 1C) narrow valleys are found instead of wide alcoves. At the ends of the ridges the 500-foot contour line is only a quarter of a mile from the shore, but it swings inland two or three miles in the valleys. Whatever cliffs there are, instead of facing the sea, face one another across deep valleys, strikingly, for example, near Sacred Falls in Kaluanui Valley.

From Hauula to the northwest end of the range (Fig. 1D) there are neither alcoves nor valleys with high and steep walls. Here the valleys are more numerous but shallower and narrower.

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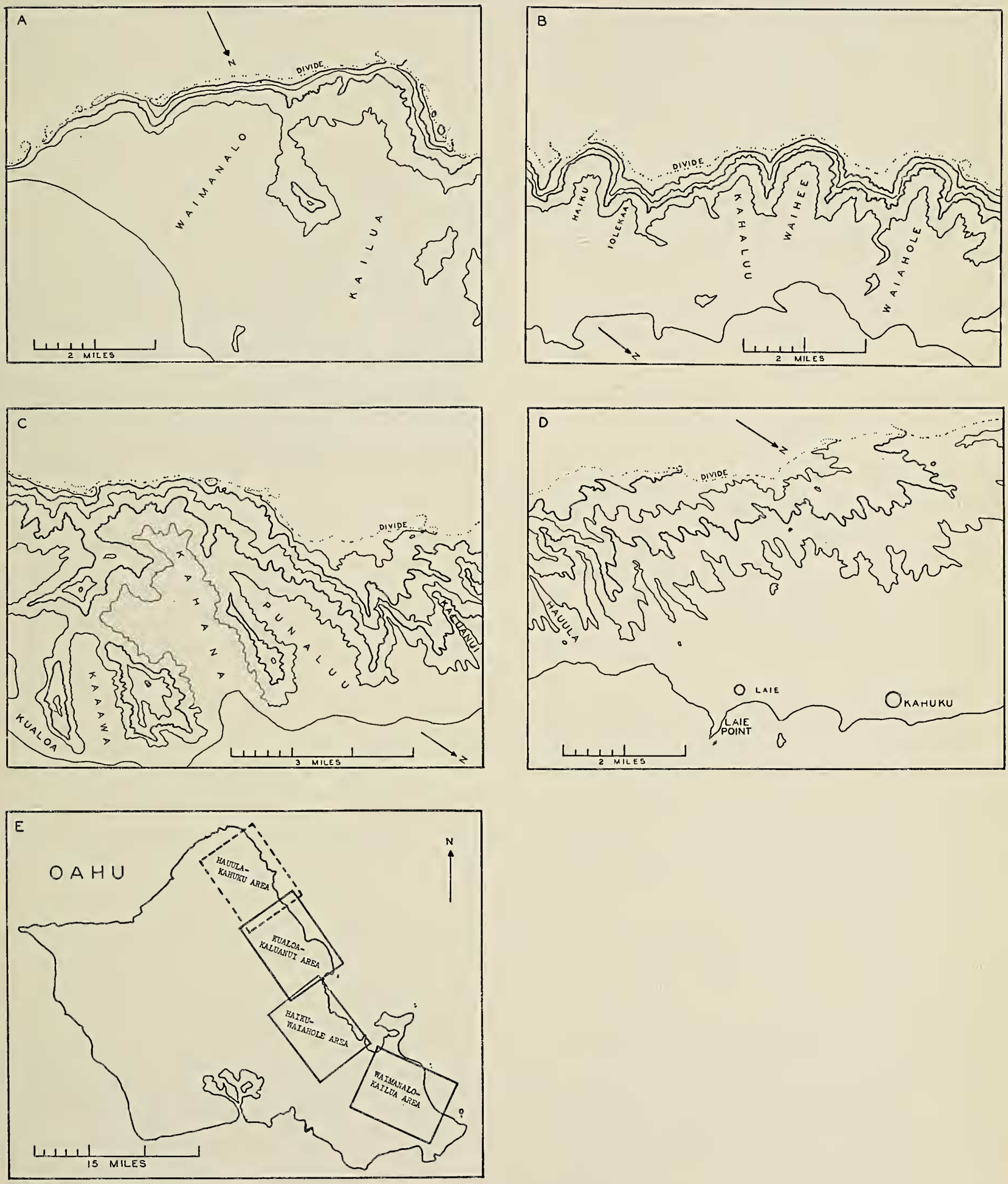

FIG. 1. Maps of the windward or northeast side of the Koolau Range. Contour interval 500 feet. A, the Waimanalo and Kailua area; B, the Haiku–Waiahole area; C, the Kualoa–Kaluanui area; D, the Hauula–Kahuku area; E, index map for A, B, C, and D.

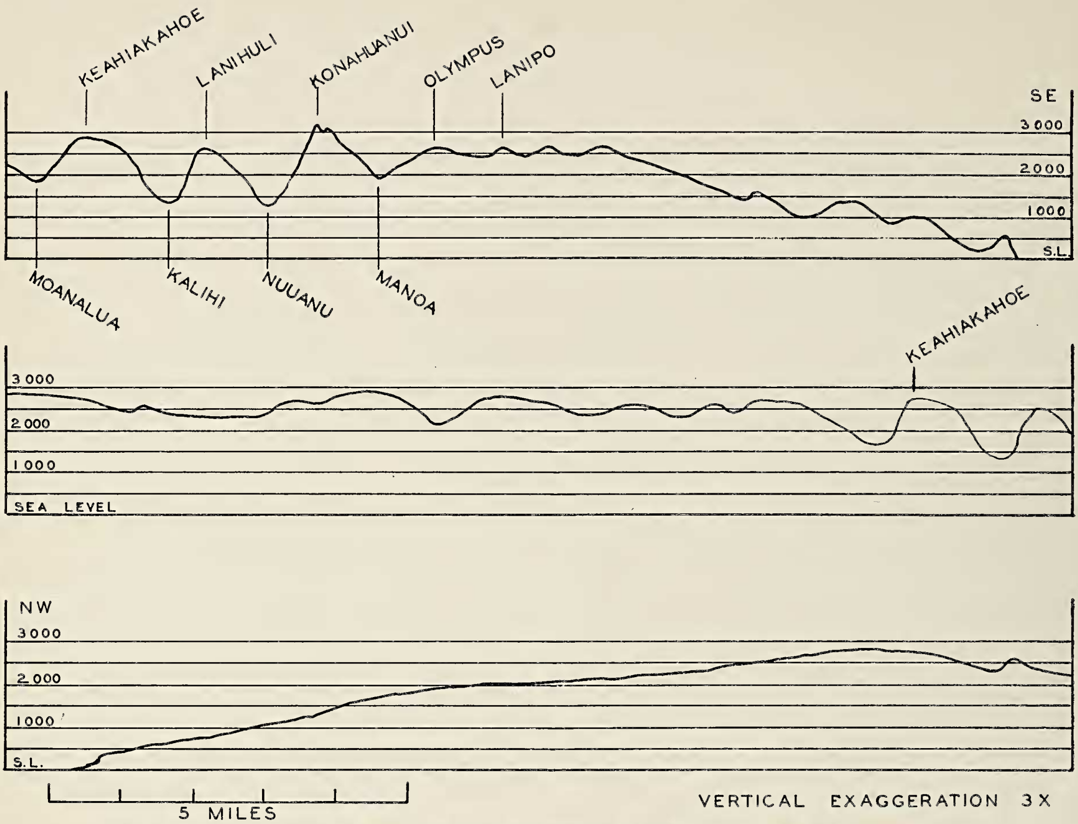

FIG. 2. Profile of the crest of the Koolau Range, with threefold vertical exaggeration.

The differences between these four areas are what would be expected if the southeastern end is the older and has thus been longer subjected to erosion. There is, of course, the additional difference that the high cliffs of the southeastern part may well be a strongly receded fault scarp.

THE SUMMIT REGION

The Crestline

The southeastern part of the crestline of the Koolau Range is deeply indented at the heads of the valleys that drain the leeward slopes, especially Manoa, Nuuanu, and Kalihi valleys (Figs. 2, 3, and 6B). The deep valleys and the deep indentations of the crestline imply prolonged erosion. In the five miles from Mt. Olympus to the head of Kalihi Valley, the crestline ranges from about 1,200 feet to 3,150 feet in altitude, a range of nearly 2,000 feet.

In contrast, the northwestern part of the crestline is only slightly indented (Figs. 2 and 4). No five-mile stretch of the crestline would range more than 1,000 feet, and perhaps no more than 500 feet in altitude. One infers that not enough time has elapsed, since constructional volcanic activity ceased, for streams to have worked headward so as to indent the crestline deeply.

The contrast in degree of indentation would be a normal consequence and indication of greater age of the southeastern end of the Koolau Range with its much deeper indentations of the crestline.

Areal Extent above 1,000 and Above 2,000 Feet

Altitudes over 3,000 feet are found in the Koolau Range only on Konahuanui (Fig. 2) in the southeastern part. Obviously there was originally a considerable area above what is now the 3,000-foot level, most of which has been removed by erosion and perhaps in part by down-faulting. Though this part of the range still has the points of greatest altitude, it has much less area above either the 1,000-foot or the 2,000-foot contour lines than the northwestern part (Fig. 5). One may again conclude that erosion has been at work much longer in the southeastern part, for it has been more fully and deeply dissected despite an originally greater altitude.

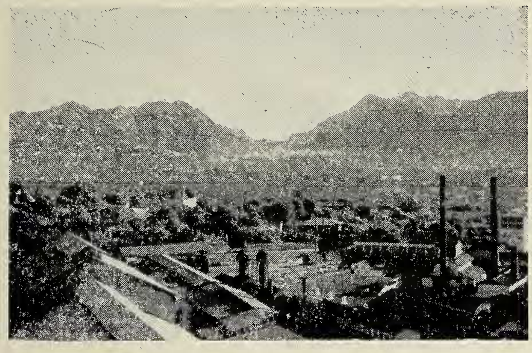

FIG. 3. Nuuanu Gap, a deep indentation of the crestline of the Koolau Range, as seen from the Hawaiian Pineapple Company cannery.

Dips of the lava flows suggest that the original summit lay distinctly northeast of the present crestline in the southeastern part of the Koolau Range, but close to the present crestline in the northwestern part of the range.

THE LEEWARD VALLEYS

The leeward valleys of the southeastern end of the range are notably wider, deeper and flatter floored than the valleys of the northwestern end (Fig. 6A–E). These characters increase from Kalama Valley, northeast of Koko Crater, to Manoa or Nuuanu (Figs. 6A and 6B), perhaps because of greater stream erosion where higher altitude caused greater rainfall and provided larger collecting basins for streams (Fig. 7, isohyetal map of Oahu). In all this southeastern part of the Koolau Range, stream erosion has been able to cut so strongly partly because of greater steepness of the original slopes leading to greater velocity and thus to stronger erosional power.

FIG. 4. The smooth crestline of the northwest end of the Koolau Range, as seen from Laie Point.

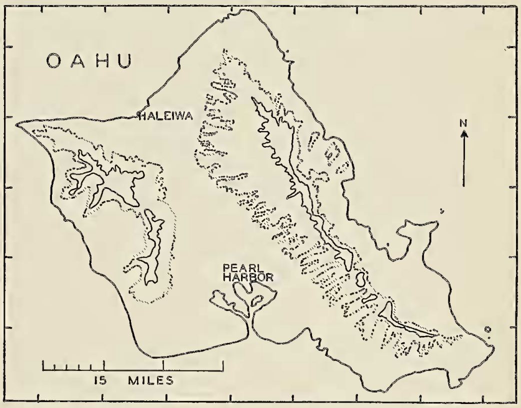

FIG. 5. The 1,000-foot (dotted line) and 2,000-foot (solid line) contour lines of Oahu.

The rather wide and level floors of Palolo, Manoa, Nuuanu and Kalihi Valleys (Fig. 6B) result in part from infilling by rather young intra-valley lava flows, but mostly from sedimentation in drowned valleys subsequent to a submergence of this part of Oahu. These valleys, and those to the east of Palolo, were cut to much their present form when this part of Oahu stood 800 or 1,000 feet higher relative to sea level than now, as shown by well logs in the Honolulu area (Palmer, 1946: 25–29). Subsidence changed the mouths of the valleys into bays, in whose quiet waters sediment accumulated to a considerable depth. Wailupe Valley (Fig. 6A) is a classic example of such a flattish valley floor (Davis, 1928: 174, fig. 74).

FIG. 6. Maps of the leeward valleys of the Koolau Range, 500-foot contour interval. A, The Kalama–Wailupe area; B, the Palolo–Kalihi area; C, the Waimalu–Waikakalaua area; D, the Kaukonahua-Kaunala area; E, index map for A, B, C, and D.

Subsidence also affected the part of the windward side from the southeastern end as far as Punaluu.

In contrast, northwest of Aiea (Fig. 6E) the leeward valleys are decidedly narrower and shallower, and to them the term "gulch" is usually applied instead of "valley" (Fig. 6C, D). Most striking are Kipapa, Waikakalaua, Kaukonahua, Poamoho and Helemano Gulches, whose sides drop rather abruptly from a fairly smooth upland surface. The map of an area of five square miles southeast of Wahiawa (Fig. 8) shows part of the extensive, smooth upland used for pineapples, with Waikakalaua Gulch and the South Fork of Kaukonahua Gulch incised for more than a

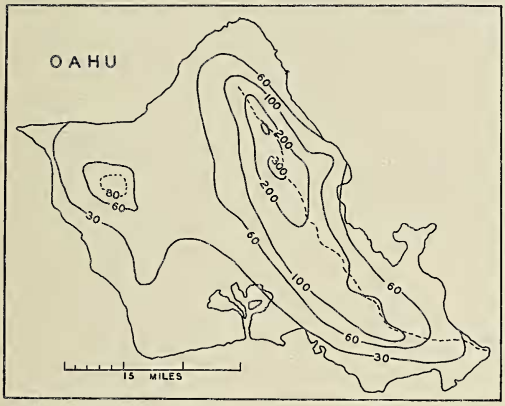

FIG. 7. Mean annual rainfall in inches on Oahu. (After the Territorial Planning Board, First Progress Report, pl. 52, p. 116. Feb. 1929.)

hundred feet. Here the upland slopes west or southwest about 200 feet to the mile, or about 2°.

In the northwestern part of the range the streams are much longer than those in the southeastern part, which operates in two ways to let only narrow gulches be cut. For one thing, the longer courses cause gentler gradients and thus less velocity and less erosive power. And also, the longer courses require the removal of a larger total volume for a given depth and width of valley, so that in a given time only narrower and shallower valleys will be cut than by shorter and steeper streams. All this is in addition to the present hypothesis that these streams have been at work for decidedly less time than the streams in the southeastern part of the range.

COURSES OF THE LEEWARD STREAMS

Comparison of two maps of the stream courses in areas, of about five square miles each, reveals marked contrasts between the ends of the Koolau Range (Fig. 9A, B). The Palolo–Waialae area, east of Manoa Valley, is characteristic of the southeastern end and the Kamananui area is characteristic of the northwestern end of the Koolau Range.

Where streams appear to have operated for a much longer time, east of Manoa, they have been able to eliminate much of their original windings in the process of cutting more and more direct courses to the sea. Their original steep gradients, down the flank of the highest part of the range, gave them greater speed and erosional energy that would favor straightening their courses.

In contrast, the streams from Kaiwikoele to Kaunala, of the northwestern Kamananui area, have much more winding courses. They began their work on less steep slopes and were therefore less strongly driven by gravity and meander more. Perhaps the gentle gradient even favors lateral swinging of the streams and meandering. When originally built the surface of a lava shield is far from smooth. Successive lava flows have steep edges and do not overlap perfectly. Their edges are

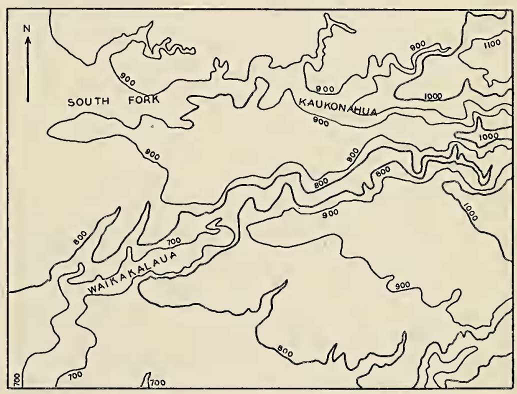

FIG. 8. Map of a smooth area of 5 square miles southeast of Wahiawa, with sharply incised gulches Contour interval 100 feet.

wavy, and these cause the streams to follow the irregularly winding low places between flows and thus to have winding courses at the start. It also appears that these streams have been at work for less time, and thus have had less time to straighten their courses.

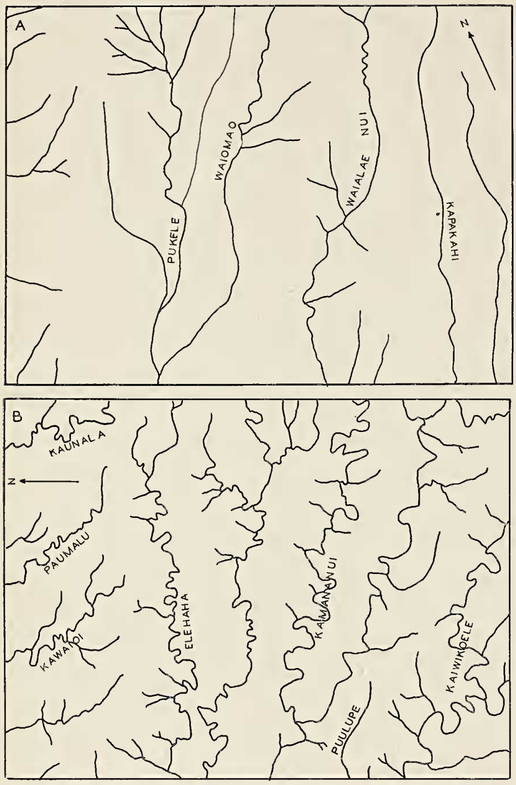

FIG. 9. Maps of stream courses, 2 by 2.5 miles. A, Palolo–Waialae area (Pukele and Waiomao are branches of Palolo Stream); B, the Kamananui area.

CROSS PROFILES OF THE LEEWARD VALLEYS

The greater degree of dissection of the older, southeastern part of the Koolau Range, as compared to the younger, northwestern part, is shown by cross profiles constructed across several adjacent valleys and the intervening ridges. Two pairs of such cross profiles are given: one pair (Fig. 10A) closer to the sea, and one pair (Fig. 10B) farther inland. The lower profile of each pair is from the southeastern part of the range, and the upper profile is from the northwestern part.

The ridges of the southeastern seaward profile (Palolo to Kalihi, Fig. 6B) show only a few small remnants of the original surface as built up by superposed lava flows, but the northwestern profile (Poamoho to Kawailoa) is made up mostly of the lava-built surface.

The southeastern inland profile (Waiomao and Pukele to Kalihi) is far more deeply incised than the northwestern profile (North Fork of Kaukonahua to Kawainui). These contrasts in the inland profiles correspond, of course, to the contrasts still farther inland, namely the contrasts in indentation of the crestline of the range (Fig. 2).

LENGTHWISE PROFILES OF CRESTS OF LEEWARD RIDGES

Profiles constructed along the crests of ridges between valleys show a marked and significant difference between the two ends of the Koolau Range (Fig. 11). (Only three profiles are shown but they are representative of the eighteen that were constructed during this study.) The lower part of each profile shows approximately the surface as it was originally built up by lava flows. These lower parts have much less rainfall than the upper parts and are much less subject to weathering and erosion. They have, of course, been lowered a little, but the triangular facets that survive do preserve fairly well the original slope and form of the lava shield.

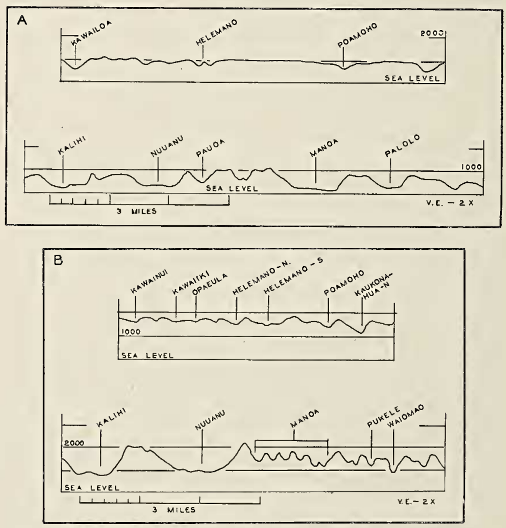

FIG. 10. Cross profiles of valleys. The upper of each pair is in the northwestern end and the lower in the southeastern end of the leeward slopes of the Koolau Range. A, Profiles farther seaward; B, profiles farther inland. Twofold vertical exaggeration.

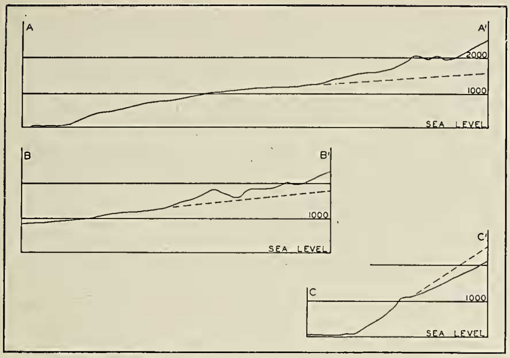

FIG. 11. Lengthwise profiles of three ridge crests. Vertical exaggeration about 5.2 times. See Figure 12 for the location of the profiles.

The profile along St. Louis Heights is what one would expect to find on a long eroded lava shield built as a *single* unit and with greater rainfall and greater erosion at the higher levels. Projection, or extrapolation, of the slope of the lower part of the profile, as shown by the broken line, runs distinctly *above* the much more eroded, much rainier, upper part of the profile.

In contrast, the profiles for the middle and northwestern parts of the range, one upslope from Wahiawa and one along the ridge on the south side of Helemano Gulch (Fig. 6D) are very different. Extrapolation of the slope of the lower part of each profile, instead of going above the rainier, more intricately dissected summit region, goes well *below* the crestline. This discrepancy leads to several hypotheses, which involve different constructional histories. The profiles are in a sense concave upward, at least for part of their extent. One thinks of lava shields as being convex upward in general, and it is the concavity that needs explanation.

Dr. Gordon A. Macdonald has pointed out to me in a letter that concave profiles are found on Hualalai, which might be due to maximum precipitation and erosion in the middle altitudes of that 8,251-foot mountain. This seems unlikely for the degree of dissection is rather uniform in all parts of Hualalai. He also points out concavities on the lower slopes of Mauna Loa, where lavas ponded against Mauna Kea, and on the lower slopes of Mauna Kea with similar ponding against the Kohala Mountains at the Waimea Saddle. In addition to these examples from the island of Hawaii, he wrote of similar concavity of the lower slopes of East Maui at the Isthmus and of East Molokai against West Molokai. An east-west profile of Mauna Kea shows concavity upward, but this may be due to the more viscous, later lavas coming to rest with steeper slopes than the older, more fluid lavas.

Ponding of lavas against the Waianae Mountains certainly has been a factor in limiting the extent of the gentle slopes of the lower parts of these profiles, as well as of the Wahiawa Plateau in general. However, there seems to be a fairly definite or sharp break in the slopes of these two profiles at about 1,200 feet altitude. Farther northwest, near Waimea Bay (Fig. 13), there is a fault with upthrow on the north side, which makes distinct breaks in profiles drawn at right angles *across* the ridge crests (Palmer, 1947, fig. 6).

The hypothesis is offered that the upper parts of these profiles (A—A′ and B—B′) represent an older long, narrow constructional land form, which was considerably eroded, and that subsequently younger volcanic activity discharged very fluid lavas that built the gentler slopes of the lower parts of the profiles. The upper parts are in regions of rather heavy rainfall and intricate dissection by streams, whereas the lower, drier parts are as yet but little dissected. These are the groups of lavas designated as K-2 and K-3 on the tentative map, Figure 19.

No petrographic evidence is known to me to indicate any marked difference in viscosity of lavas in these areas.

LATE VOLCANIC ACTIVITY

Three main volcanic episodes have long been recognized for Oahu. The first, which Stearns (1935) divided into three subepisodes, built the lava shield from which the Waianae Range has been carved. The second was thought to have built the shield of the Koolau Range. In the third episode a number of pyroclastic cones and craters, such as Diamond Head, and several intra-valley flows were erupted, constituting the Honolulu Volcanic Series of Stearns.

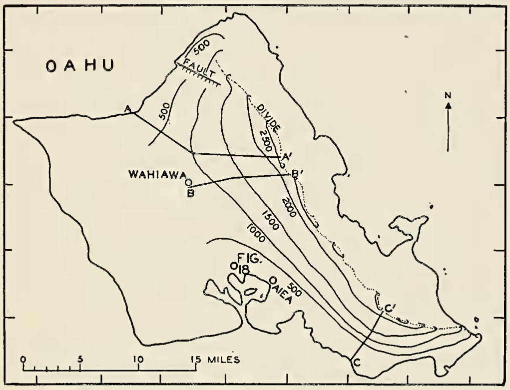

FIG. 12. Envelopes of the 500–, 1,000–, 1,500–, 2,000– and 2,500-foot contour lines on the lee side of the Koolau Range. The lines A—A[1], B—B[1] and C—C[1] show the locations of the profiles of Figure 11. Small circles give the locations of Wahiawa, Aiea, and the view in Figure 18.

One unexplained peculiarity of the last episode is that it seemed to be restricted to the part of the Koolau Range southeast of a line from Pearl Harbor to Kaneohe. (Several young structures lie on the south end of the Waianae Range, and may be of about the same age.)

Was anything happening northwest of that line?

The hypothesis here offered is that there was a large amount of eruptive action northwest of the line, more or less at the time that Diamond Head (Fig. 13) and the rest were active. At least this was after the Koolaus had been considerably eroded. This activity involved the quiet effusion of a large amount of very fluid lava, which flowed out to form very gently sloping surfaces. This hypothesis would account for the extensive, rather smooth, lava-built surface known to many as the Wahiawa Plateau. It would also explain the profiles of the ridge crests in the middle and northwestern parts of the Koolau Range. The vents that supplied these lavas would have been located more or less parallel to the Koolau crestline, but down the leeward side a way. If their altitudes were fairly low, like the altitudes of many of the vents of the Honolulu Volcanic Series, they would readily build a plateau that would overlap the lower slopes of the northwest end of the main Koolau Range, as it then was, filling in the valleys and partly burying ridges. The lavas, of course, also overlapped the lower slopes of the Waianae Range.

The southwest rift of Mauna Loa, on the island of Hawaii, is marked by cones, cracks, and fissures from which great volumes of lava

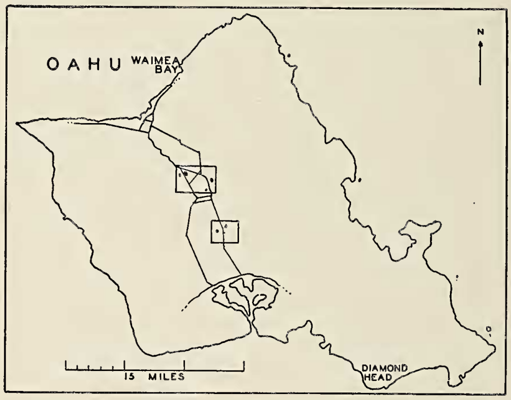

FIG. 13. Index map for Figures 14 and 16, the maps of lateral lava shields.

have been poured out to mantle the slopes of the mountain. The volume of lavas far exceeds the volume of pyroclastic materials erupted from the rift. At the south end, this rift on Mauna Loa is marked by a great fault at Ka Lae, with the shoreline of the downthrown, western side offset about two miles inland as compared to the upthrown, eastern side.

A rather similar fault offsets the shore line of Oahu about two-thirds of a mile at Waimea Bay (Fig. 12), at the northwest end of the Koolau Range. The similarity of the Waimea Fault to the Ka Lae Fault suggests that a rift extends eastward from Waimea Bay, and that it may well have determined the location of the vents that yielded the lavas that built the Wahiawa Plateau and related, rather smooth surfaces.

ENVELOPES OF CONTOUR LINES

The levelness of the Wahiawa Plateau, or the gentleness of its slopes, is brought out by a study of the "envelopes" of the 500-,

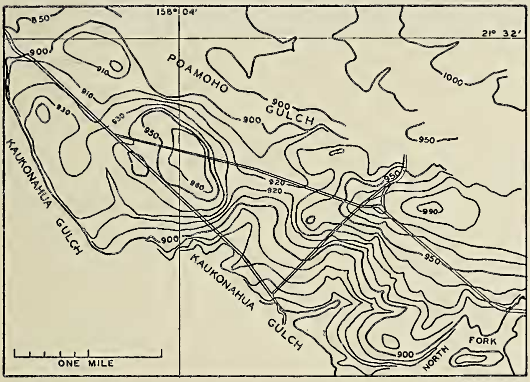

FIG. 14. Map of lateral lava shields northwest of Wahiawa. Contour intervals of 10 and 50 feet.

1,000-, 1,500-, 2,000- and 2,500-foot contour lines on the lee side of the Koolau Range (Fig. 12). The envelopes were constructed by marking the down-slope salients of the respective contour lines on the 1938 U. S. Geological Survey topographic map of Oahu, on the 1:62,500 scale. Then the salients were joined freehand by a smooth line, thus outlining the original form of the volcanic pile.

It will be noted that in the southeastern area the selected envelopes are only a mile or so apart, in general, indicating fairly steep slopes. In the northwestern part, however, they are in general twice as far apart indicating the gentler slopes of the suggested, additional volcanic episode.

LATERAL LAVA SHIELDS

There is no definite evidence as to the location of the eruptive vents that supplied most of the lavas that built the Wahiawa Plateau and its related surfaces. The suggested prolongation of the Waimea Fault as the locus of vents is only an hypothesis.

There are, however, certain minor, lateral vents indicated by half a dozen low but broad hills between Kipapa Gulch and Poamoho Gulch (Fig. 13). These small hills slope gently outward in *all* directions from their low summits, so that their slopes are in part in the reverse direction to the usual, roughly westward slope of the "plateau." Although they are much smaller they resemble to some degree the lateral lava shield named Maunaiki, which was built by a flank eruption from the southwest rift of Kilauea in the winter of 1919–1920. Lava that had drained from Halemaumau is thought to have moved underground along the rift for a way, and then to have come to the surface to build Maunaiki. Such structures are called lateral lava shields.

Three of the lateral lava shields, northwest of Wahiawa, are aligned as if their lavas had come from points along a rift or fissure bearing about N. 70° W. (Figs. 14 and 15). Two lateral lava shields, a little south of the Waiahole Aqueduct, one on either side of Kamehameha Highway, suggest a fissure bearing about S. 80° W. (Figs. 16 and 17).

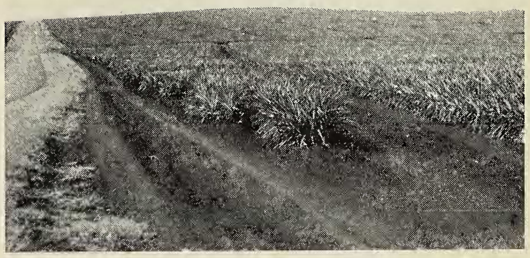

FIG. 15. The lateral lava shield in the northwest corner of the big triangle of roads in Figure 14.

Stearns (1940: 5 and pl. 1) suggested that the unexpectedly high ground water body, in the central part of the Wahiawa Plateau, was held up between dikes, and gave a map showing by two boundary lines the presumed extent of the high-level ground-water body.

The groups of small lava shields here described may well have been supplied with lava from such dikes. The dikes are, of course, transverse to the supposed rift that supplied most of the lavas for the Wahiawa Plateau.

The lava shields are too low to be shown by the 100-foot contour interval of the 1938 edition of the U. S. Geological Survey's topographic map of Oahu. It happens that the 40-foot interval of the 1917 U.S.G.S. map does have closed contour lines around four of the lava shields. The maps of Figures 14 and 16 were prepared from the photolithographic preliminary sheets for the 1938 edition. These preliminary maps are on the scale of 1:20,000, and have two contour intervals, 50 feet in the more rugged areas and only 10 feet in the smoother areas, which brings out the lava shields very clearly.

UNCONFORMITIES

In sedimentary rocks one often finds unconformities or marked differences between

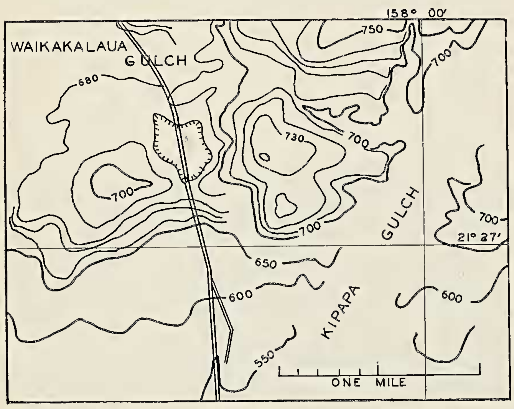

FIG. 16. Map of lateral lava shields between Kipapa and Waikakalaua Gulches. Contour intervals of 10 and 50 feet.

lots of strata deposited at different times. One lot may have a different attitude or inclination from the other, or they may differ in kinds of fossils, or kinds of rock, or the older may have weathered at its top to soil. Fossils cannot help in separating two lots of lavas made at different times, nor can differences in rock types often help in Hawaii where the rock

FIG. 17. The lateral lava shield east of the depression in Figure 16.

types are in general very similar. In a few places in Hawaii, however, older and younger lots of lava flows are separated by angular unconformities, where the older flows were truncated or bevelled and the newer flows mantled the eroded or faulted surfaces of the older flows. No such unconformities are known within the Koolau Range proper, although the Honolulu Volcanic Series lies unconformably on Koolau lavas in most places.

Some unconformities may have the older and younger lots of strata or lava flows in essentially parallel position, but with a deeply weathered zone at the top of the older series that implies a considerable time interval between the making of the older and the younger lots of rock. A possible example of such an unconformity has recently been exposed in a road cut on the north side of Kamehameha Highway about 0.7 miles west of Pearl City Junction (Fig. 18). This is not a conclusive example for it may be merely a lesser unconformity within one of the larger bodies of lavas.

GEOLOGIC HISTORY OF THE KOOLAU RANGE

The various topographic contrasts within the Koolau Range, to which attention has been called, lead to modifying the history of the Koolau Range as heretofore envisioned (Dana, 1890: 301; Dutton, 1894: 212–215; Hitchcock, 1900; Hitchcock, 1911: 42–44). (The history of the Waianae Range is omit-

FIG. 18. Possible unconformity 0.7 miles west of Pearl City Junction. See Figure 12 for the location.

ted, except to note that the Waianae Lava Shield had been built and considerably eroded before the Koolau vents discharged any of the flows that overlap the east side of the Waianae Range.)

According to the new interpretation, the first Koolau episode was the building of the southeastern end of the present Koolau Range, making a somewhat elliptical dome or shield with a base of the order of 15 by 20 miles. The lavas of this episode are named "K-1" on the tentative map (Fig. 19). Flows on the leeward side dip 6° to 9° (Stearns, 1939, pl. 2). Those on the windward side presumably had similar dips, but this cannot be observed because so much of the original shield has been removed. When this eruptive activity died out, stream erosion became dominant and deep valleys were cut in the dome. It is my opinion that a considerable part of the windward side of this shield was dropped down along a fault or fault zone, and that the fault scarp has receded some miles as a result of various erosional processes.

Subsidence of part of the shield lowered the Honolulu area 800 or 1,000 feet. Data are not available for estimating the lowering in the Waimanalo and Kailua part of the windward side, but the fairly wide and level floors of Punaluu and Kahana valleys suggest subsidence of a few hundred feet, followed by sedimentation in the bays made by drowning the valley mouths. Northwest of Punaluu there is little or no evidence of significant subsidence of the windward side.

It is now suggested that a second episode of volcanic activity built a somewhat elongated ridge northwestward for 20 or more miles from the northwest end of the first oval shield. This ridge was about ten miles wide, and was built of the lavas that came up along numerous sub-parallel dikes of the "dike complex." It is indicated as "K-2" on the tentative map (Fig. 19). Though on a much smaller scale it is somewhat analogous to the ridge that has been built up by lavas from the southwest rift of Mauna Loa. Stearns (1939, pl. 2) reports dips of 7° to 10° on the windward side of this part of the Koolau Range. Data on dips are probably not obtainable on the leeward side, but are presumably similar.

Dividing the constructional history of the higher parts of the Koolau Range into two

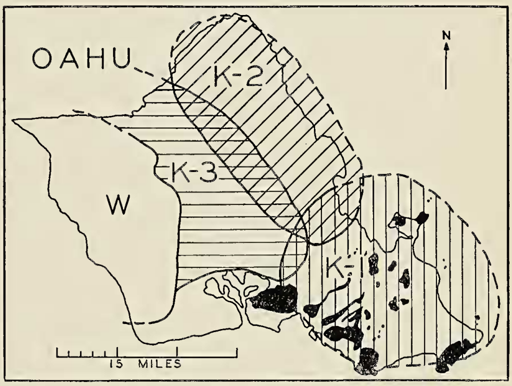

FIG. 19. Tentative map of areas built during the suggested eruptive episodes in the construction of the Koolau Range. The Honolulu Volcanic Series, solid black, is from Wentworth and Winchell (1947).

episodes, K-1 and K-2, will explain the contrasts between the southeastern and northwestern ends as regards (1) the windward aspect, i.e., alcoves vs. valleys, (2) the degree of indentation of the main crestline, (3) the relative amounts of area above the 2,000-foot level, (4) the shapes of the leeward valleys, and (5) the inland pair of cross profiles (Fig. 10B). The isohyetal map (Fig. 7) shows abundant, and about equally abundant, rainfall along the upper parts of the whole range, so that differences in rainfall cannot account for the geomorphic contrasts. In fact, the areas of greatest rainfall, 300 inches a year, are in the less deeply eroded northwestern part.

After eruption of the K-2 series of lavas, there came another erosional episode, during which streams not only cut into this new ridge but also continued their work in the older part. Vigorous wave erosion may have commenced at this time or later, but the northwest end of the new ridge has been cut back by sea cliffs, which now survive as somewhat subdued cliffs from a little west of Kahuku nearly to Haleiwa (Fig. 6D). Wave action has also truncated various spurs on the windward side, especially from Kualoa to Hauula (Fig. 1C, D).

Next in our story, the last Koolau eruptive episode or episodes occurred. For one of these we have the "Honolulu Volcanic Series" of Stearns (1935) which built various pyroclastic cones and poured out several intra-valley lava flows in the Honolulu area, or the southeastern end of the Koolau Range. That the Honolulu Volcanic Series postdates the building of the southeastern part of the range is very clear from the unconformable positions and from the topographic youth of the cones, and flows.

The other late episode or sub-episode was the effusion of a large amount of very fluid lavas from the leeward side of the northwestern (K-2) ridge of the Koolau Range to build the smooth Wahiawa Plateau with gentle slopes leading not only toward the Waianae Range but also both ways, toward Pearl Harbor and toward Haleiwa, from the low divide between Waikakalaua and Kaukonahua streams. Small eruptions from transverse dikes or rifts built the various lateral lava shields. The lavas of the plateau and of the small shields constitute the K-3 series of the tentative map. There is no evidence in the structures by which to determine the relative age of the K-3 series and the Honolulu Volcanic Series, as they do not overlap, or no overlap of one on the other is exposed, nor is any recorded in well logs.

Perhaps the fact that pyroclastics are abundant in one and lacking in the other indicates that the two are of different age. Another difference is that the Honolulu Volcanic Series affected both the windward and leeward sides of the range, whereas the K-3 series is restricted to the leeward side.

An attempt to map the extent of the eruptive products of the several episodes must of necessity be tentative, because subsequent weathering and erosion have masked the former boundaries. To such extent as boundaries exist, they are those marked by topographic differences.

Separation of the K-3 and the K-2 lots of lava from one another will explain several topographic contrasts. The upper profile in Figure 10B is in the region of the K-2 Series, and has none of the original upland surviving as there is in the upper profile of Figure 10A, in the K-3 region. This, however, may be partly, or largely, a matter of differences in rainfall and in distance between stream courses. The profiles A—A′ and B—B′ in Figure 11 have a change of slope at the boundary between K-2 and K-3. And in Figure 12, the wide separation of the lower contour lines marks the area of the fluid K-3 lavas. Finally, the smoothness of the Wahiawa Plateau as a whole and the rather sharp incision of the gulches indicate the youth of the K-3 area as compared to the K-2 area.

The story concludes with the erosional episode that is going on at present. It continues the earlier erosional events on the older areas but began on the Honolulu Volcanic Series and on the K-3 Series when their eruptive activity ended. This episode is much complicated by the several glacially controlled oscillations of sea level, which are omitted as this paper is concerned primarily with the volcanic constructional events.

REFERENCES

DANA, JAMES DWIGHT. 1890. *Characteristics of volcanoes.* xvi + 399 pp., 16 pls., figs. Dodd, Mead & Co., New York.

DAVIS, WILLIAM MORRIS. 1928. *The coral reef problem.* v + 596 pp., 227 figs. American Geographical Society, Special Publication No. 9, New York.

DUTTON, CLARENCE EDWARD. 1884. Hawaiian volcanoes. *U. S. Geol. Survey, Ann. Rpt.* 4: 75–219, 3 figs., 30 pls.

[HAWAII] TERRITORIAL PLANNING BOARD. 1939. *First Progress Report.* [xvi] + 322 pp., 26 figs., 150 pls. Ter. of Hawaii, Planning Board, Honolulu.

HITCHCOCK, CHARLES H. 1900. Geology of Oahu. *Geol. Soc. Amer., Bul.* 11: 15–60.

——— 1911. *Hawaii and its volcanoes.* viii + 314 pp., 52 pls. The Hawaiian Gazette Co., Ltd., Honolulu.

PALMER, HAROLD S. 1946. *The geology of the Honolulu ground water supply.* iv + 55 pp., 17 figs. Board of Water Supply, City and County of Honolulu, Honolulu.

——— 1947. Fault at Waimea, Oahu, *Pacific Sci.* 1 (2): 85–91.

STEARNS, HAROLD T. 1939. *Geologic map and guide of the Island of Oahu, Hawaii.* x + 76 pp., 23 figs., 1 map. Ter. of Hawaii, Div. Hydrog. Bul. 2. Honolulu.

——— 1940. *Supplement to the geology and ground-water resources of the Island of Oahu, Hawaii.* vii + 164 pp., 6 pls., 8 figs. Ter. of Hawaii, Div. Hydrog., Bul. 5. Honolulu.

STEARNS, HAROLD T., and KNUTE N. VAKSVIK. 1935. *Geology and ground-water resources of the Island of Oahu, Hawaii.* xx + 479 pp., 33 pls., 34 figs. Ter. of Hawaii, Div. Hydrog. Bul. 1. Honolulu.

WENTWORTH, CHESTER K., and HORACE WINCHELL. 1947. Koolau basalt series. *Geol. Soc. Amer., Bul.* 58 (1): 49–77.